LANSCE DIVISION TECHNOLOGY REVIEW

Mercury Target Development Tests for the Spallation Neutron Source at the Weapons Neutron Research Facility

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For several years, Oak Ridge National Laboratory (ORNL) researchers have been collaborating with researchers from the Weapons Neutron Research Facility (WNR) at the Los Alamos Neutron Science Center (LANSCE) to study issues associated with using mercury as the target material for the Spallation Neutron Source (SNS). Mercury was selected as the target material for the SNS because of its favorable neutron-production characteristics and potential to handle the high-proton-beam power (2 MW) that is planned for this facility. An important issue identified for liquid-metal targets in pulsed sources is their ability to withstand the rapid pressure increase when they are irradiated by the pulsed proton beam. Although a WNR pulse contains much less energy than a pulse for the 2-MW SNS, focusing the WNR proton beam in the Blue Room down to a size of about 20 mm in diameter will allow us to reasonably simulate the beam intensity, and therefore the pressure increase, expected for the SNS. Previous tests with an array of target shapes, diagnostics, and instrumentation measured the vessel strain to ensure that the target can sustain the dynamic pressure loads. Besides providing data that are helping the SNS team to design and analyze the actual SNS target, these tests successfully demonstrated that a newly developed fiber-optic-based strain-measurement system could function in this demanding radiological environment.

Understanding Pitting in Irradiated Targets

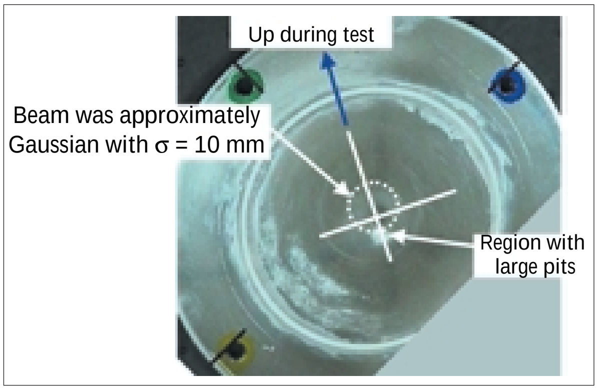
Tests conducted during 2001 were designed to examine whether the pressure pulse caused pitting damage to the stainless-steel container for the mercury. The pitting phenomenon was first identified as a potential concern by a team of researchers at the Japan Atomic Energy Research Institute, where they observed pitting of stainless-steel surfaces that were in contact with mercury subjected to large, mechanically induced pressure pulses. As such, we then need to discern whether the surfaces of mercury-target vessels become pitted with comparable beam-induced pressure pulses. This issue could not be resolved from examinations of targets previously irradiated at WNR because these targets were not inspected before irradiation and the roughness of the surfaces was too great to distinguish between beam-induced pits and other imperfections in the surface of the materials.

Because of the urgency to complete the SNS target design, we conducted two experiments in 2001 to study the pitting issue—in July and December. One of the two targets used in July 2001 is shown in Fig. 1. This type of cylindrically shaped target is referred to as a "large-effect" (LE) target and was first used in the strain measurements to obtain an easily measured "large" strain in the thin diaphragms that were incorporated in the end plates/flanges.

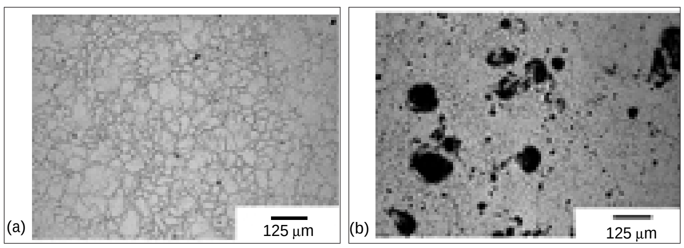
↑ **Fig. 1.** *LE target used for the July 2001 mercury-target-pitting tests in the Blue Room at WNR. Thin diaphragms were used in these tests to achieve large strains.*

All four of the diaphragms tested in July 2001 were fabricated from 316-type stainless steel in the annealed condition. Three of four were used directly in the LE targets, whereas the fourth was treated with a surface-hardening technique. This treated diaphragm was used on the rear (proton-beam exit) end of one of the two LE targets.

A photograph of the mercury-facing surface of one of the untreated diaphragms is shown in Fig. 2. As shown in the photo, large pits, visible to the naked eye, are distributed over a region that is about 5 mm in diameter and centered about 10 mm directly below the center of the diaphragm. Using activation-analysis techniques, the beam was centered approximately 5 mm directly above the center of the diaphragm. This 180º shift between the beam and the pit region



↑ Fig. 2. *This thin diaphragm flange was exposed to mercury in the July 2001 tests in the Blue Room at WNR. The cross marks the center of the diaphragm and the circle indicates the 1-σ boundary of the approximately Gaussian-shaped beam. Large pits were clustered in a region symmetric to the center of the beam relative to the center of the diaphragm. This shift may be caused by the radial focusing of the pressure wave.*



↑ Fig. 3. *This image shows micrographs of a stainless-steel diaphragm from one LE target used in the July 2001 mercury-target-pitting tests: (a) a typical region before beam exposure, and (b) a section near the center of the diaphragm containing large pits that were formed by exposure to 200 pulses in the Blue Room at WNR. These large pits had diameters of up to approximately 100 µm. Small, randomly distributed pits were also found on the bare surface of the three annealed stainless-steel specimens. Large pits were found, to a lesser extent, on the one diaphragm that was treated with a hardening process, and dramatically fewer small, randomly distributed pits were detected.*

may be due to radial focusing of the pressure wave and its reflection off of the side walls of the cylinder.

Micrographs of the surface of one of the untreated diaphragms before and after exposure to 200 nearly full-current pulses from the Proton Storage Ring (PSR) are shown in Fig. 3. Evidence for pitting is obvious in these images. In carefully examining the diaphragm surfaces, two categories or types of pits were observed: (1) large (~ 100-µm-diam) pits that appeared in a cluster near the center of the diaphragm, as shown in Fig. 2, and (2) randomly distributed, small (~ 10-µm-diam) pits. Large and small pits occurred on both the front (beam entrance) and rear (beam exit) of the untreated diaphragms. Although some of the large pits clustered near the center of the diaphragm were found on the surface-hardened diaphragm, dramatically fewer randomly distributed pits could be detected at the resolution used to perform the inspections (~ 5 µm). Based on the July 2001 test results, we concluded that mitigating this pitting damage is required to ensure that the mercury target can achieve an acceptable lifetime at the SNS. With this in mind, the December 2001 tests were dedicated to further examine the pitting phenomenon and to look at possible elimination, or at least reduction, of the pitting problem.

Seven mercury targets were tested in December 2001. Four of these targets used different shapes or different diaphragm materials and were exposed to 200 beam pulses. Most notably, we used a target with a rectangular cross section in an attempt to eliminate the postulated radial focusing of the pressure wave. Also, we tested diaphragms with increased thickness in an attempt to reduce the large stresses. Two targets were also tested with only 20 pulses to determine whether future experiments might be possible at this reduced fluence level. Finally, a lead-bismuth target, with geometry and materials essentially the same as that used in July 2001, was exposed to the WNR beam for 200 pulses. This experiment was done in collaboration with the LANSCE team working on the lead-bismuth target design for the Advanced Accelerator Applications program. Examination of the December 2001 irradiated targets will begin in late February 2002 following their shipment from Los Alamos National Laboratory to ORNL after extensive decontamination and health-physics inspections.

Conclusion

Further Blue Room tests to examine alternative mitigation schemes and the threshold for pitting damage are proposed for July 2002. Specific plans must await results of the inspection of the targets irradiated in December 2001. Our next tests will likely be the final tests before committing to construction of the SNS target.

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